

(19) World Intellectual Property Organization  
International Bureau



(43) International Publication Date  
25 October 2001 (25.10.2001)

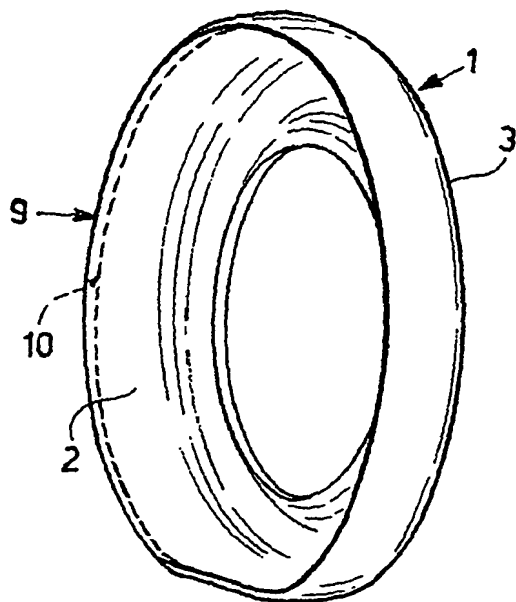
PCT

(10) International Publication Number  
**WO 01/80327 A1**

- (51) International Patent Classification<sup>7</sup>: **H01L 41/113**, B60C 23/06, 23/04, 23/20 (74) Agents: **MARCHI**, Massimo et al.; Via Pirelli, 19, I-20124 Milano (IT).
- (21) International Application Number: PCT/EP01/04210 (81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.
- (22) International Filing Date: 12 April 2001 (12.04.2001)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:  
00830292.9 18 April 2000 (18.04.2000) EP  
60/218,829 18 July 2000 (18.07.2000) US
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- Published:**  
— with international search report  
— before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments

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(54) Title: **PIEZOELECTRIC GENERATOR FOR SENSORS INSIDE VEHICLE TYRES**



(57) Abstract: A system for generating electrical energy in a vehicle tyre (1) comprises at least one piezoelectric element (9, 109) associated to the tyre (1) which generates electrical energy whenever it is deformed, and this piezoelectric element (9, 109) is elongate, extends along at least a portion of the tyre (1) and is connected electrically to an electrical circuit that is applied to the said tyre (1) and is not in electrical communication with the vehicle. The piezoelectric element (9, 109) preferably comprises a coaxial cable (10) extending along a straight or undulated path of the tyre circumference.

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## PIEZOELECTRIC GENERATOR FOR SENSORS INSIDE VEHICLE TYRES

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The present invention relates to a system for generating and using electrical energy in a vehicle tyre and a tyre equipped with this system.

More specifically, the present invention relates to a system for generating electrical energy while a vehicle is in motion, this energy also being able to be stored for use in the said tyre even when the vehicle is stationary.

US 4,504,761 discloses an electricity generating apparatus comprising

- a motor vehicle having an electrical system comprising a battery and a plurality of assemblies comprising a wheel and a tyre having a rubber envelope comprising a first annular band and a second annular band that has a plurality of projections positioned close to the first band so as to move towards it in response to rolling movements of the tyre; and
- means for generating electricity in response to movements of the motor vehicle along a road comprising
  - a multiplicity of piezoelectric elements fixed to the first band and positioned close to the projections so as to engage with them during the rolling movement of the tyre in order to generate electricity in response to the rolling movement of the tyres with respect to the road; and
  - means of interconnection of the piezoelectric elements in a circuit with the battery to supply electrical energy, generated by the piezoelectric elements, to the battery, the said means having output conductors.

The electricity generating system in that patent exhibits many disadvantages. The bands carrying the piezoelectric elements and the

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projections which activate them require the existence of a sort of chamber in the tyre. This requires a profound modification of the structure of the tyre and significantly increases the costs of manufacture. It also increases the weight of the tyre and thereby adversely affects its performance, such as rolling resistance and comfort.

In addition, the fitting of the various piezoelectric elements in their band and the formation of the inductive systems necessary to transmit the electrical energy produced to the battery of the motor vehicle are very complex and expensive.

It is also known that it has been proposed that various types of sensors be installed in the tyre, e.g. pressure, temperature, force, velocity sensors and the like, to monitor and control the performance of the tyre and/or of the vehicle. These systems however require an electrical power supply system for the operation of the sensor and/or of the transmitter which transfers out the data and information collected by the sensor.

The power supply systems proposed hitherto are essentially of two types.

The first type consists of inductive systems or sliding-contact systems such as that required in US 4,504,761, except that the electrical energy is transferred from the vehicle battery to a sensor and/or transmitter located in the tyre. However, as we have already seen, these systems have the drawback of being very complicated and expensive.

The second type meanwhile consists of a cell mounted inside the tyre. However, even the most sophisticated and expensive cells eventually run down and replacing them with a new cell inside the tyre will be a nuisance and expensive for the user of the vehicle.

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The industry is therefore still highly conscious of the need for a system able to power a sensor and/or a transmitter located inside a tyre of a vehicle wheel that will be simple, cheap and not inconvenience the user of the vehicle.

The inventors have now realized that this objective can be achieved by means of a piezoelectric element associated to a tyre without requiring any modification to the conventional tyre structure.

In its first aspect, the present invention relates to a system for generating electrical energy in a vehicle tyre comprising at least one piezoelectric element associated to the said tyre which generates electrical energy whenever it is deformed, the said tyre also comprising a carcass and a tread and being mounted on a vehicle wheel rim, characterized in that the said at least one piezoelectric element is elongate, extends along at least a portion of the said tyre and is connected electrically to an electrical circuit that is applied to the said tyre and is not in electrical communication with the vehicle.

In its second aspect, the present invention relates to a tyre for a vehicle comprising at least one piezoelectric element that generates electrical energy whenever it is deformed, the said tyre also comprising a carcass and a tread and being characterized in that the said at least one piezoelectric element is elongate, extends along at least a portion of the said tyre and is connected electrically to an electrical circuit that is applied to the said tyre and is not in electrical communication with the vehicle.

In a first preferred embodiment, the said electrical circuit comprises a sensor for monitoring and controlling the performance of the tyre and/or of the vehicle.

Typically, the said sensor is selected from pressure, temperature, force, velocity sensors and the like.

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In a second preferred embodiment, the said electrical circuit comprises a transmitter that transmits out of the tyre the data collected by the said sensor.

Preferably, the said transmitter is operationally connected to a receiver installed in the vehicle. In this way the data acquired by the sensors operating inside the tyre are processed by suitable devices installed on the vehicle in order to initiate actions designed to regulate/optimize the behaviour of the moving vehicle during cornering and/or when travelling in a straight line, as described in European Patent Applications No. 99830714.4 filed on 18 November 1999, and No. 00830041.0 filed on 25 January 2000, in the present Applicant's name.

Typically, the said transmitter is a radio transmitter.

In a third preferred embodiment, the said electrical circuit includes a device that stores the electrical energy produced by the said piezoelectric element.

Advantageously, the said storage device is a capacitor/rechargeable battery assembly that acts as a buffer battery.

The arrangement of the said elongate piezoelectric element and its length are not of critical importance. However, it is preferable to attach it to an inside surface of the said tyre carcass because fitting it here is very economical.

Still more preferably, the said elongate piezoelectric element is laid with an undulated path along the circumference of the tyre. This makes it possible to have a continuous output of power.

A typical example of an elongate piezoelectric element according to the invention is a coaxial piezoelectric cable comprising a central core of electrically conducting material, an electrically insulating layer made of a piezoelectric polymer, a braided conductor made of an electrically conducting material, and a sheath.

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The said electrical circuit and its components are preferably also attached to an inside surface of the said carcass for the reasons already given on the subject of the said elongate piezoelectric element.

In the course of this description and the claims, the expression "elongate piezoelectric element" is used to indicate a piezoelectric element whose length is at least 2 times, preferably at least 3 times, and still more preferably at least 5 times greater than its width or diameter. The length of the said "elongate piezoelectric element" is preferably at least 30 mm because otherwise it does not have sufficient sensitivity to the deforming variations imposed on any portion of the tyre during its rotation.

The features and advantages of the invention will now be explained with reference to an embodiment shown by way of non-restrictive example in the accompanying figures, where:

Fig. 1 shows a system for generating electrical energy comprising a piezoelectric element associated to a vehicle tyre and produced in accordance with the invention, the tyre being shown in perspective and in a half section on an equatorial plane;

Fig. 2 is a cross section through the tyre of Fig. 1;

Fig. 3 shows a variant of the tyre of Fig. 1;

Fig. 4 is an end-on perspective view on a larger scale of the piezoelectric element of Fig. 1;

Fig. 5 is a side view of the piezoelectric element of Fig. 4;

Figs 6 and 7 show diagrammatically a number of components of an electrical circuit applied to the tyre of Fig. 1;

Fig. 8 is a graph showing the potential difference generated by the piezoelectric element of Fig. 1 against time; and

Fig. 9 is a graph showing the voltage generated by the piezoelectric element of Fig. 1 against the velocity of the vehicle.

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Figs 1 and 2 show a vehicle tyre 1 comprising a carcass 2, a tread 3, belt plies (belt pack) 4, sidewalls 5 and beads 6. The carcass 2 has an inside surface 7, optionally covered with a liner. The tyre 1 is mounted on a wheel rim 8. According to the invention an elongate piezoelectric element 9 formed by a coaxial piezoelectric cable 10 is associated to the tyre 1. The piezoelectric cable 10 is attached to the inside surface 7 of the carcass 2. The cable 10 extends all the way around the equatorial circumference of the inside surface of the carcass in a longitudinal direction (direction X, orthogonal to the plane YZ), that is, in the direction in which the vehicle is travelling. The piezoelectric cable 10 may also extend circumferentially along a sidewall 5 of the tyre 1 or only along a portion of the circumference (an arc of the circumference).

Fig. 3 shows an elongate piezoelectric element 109 formed by a coaxial piezoelectric cable 10 that extends along the equatorial circumference, following an undulated path.

As shown in Figs 4 and 5, the piezoelectric cable 10 comprises a central core 11 of electrically conducting material, an electrically insulating layer 12 and a braided conductor 13, also made of electrically conducting material. The core 11 may be made of e.g. strands of brass-coated steel wire while the conductor 13 is copper. The electrically insulating layer 12 is interposed between the core 11 and the conductor 13 and consists of a piezoelectric polymer such as polyvinylidene fluorinated (PVDF) for example. Fitted over the conductor 13 is a protective outer sheath coating 14 of elastoplastic material, e.g. polythene or halobutyl rubber. The piezoelectric cable 10 has a diameter of for example approximately 3mm.

In the embodiments illustrated in Figures 1, 2 and 3, the piezoelectric cable 10 is attached to the inside surface 7 of the carcass 2, but can also be embedded within the carcass 2, where it can replace

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one of the cords of the carcass 2 ply, within the belt 4 where it can replace a belt cord, or in the tread 3, where it can be applied inside a circumferential groove of the tread 3, preferably in the bottom of a groove.

When the piezoelectric layer 12 is caused to deform at a certain speed, it generates a potential difference between the central core 11 and the conductor 13. This potential difference is proportional, typically in a linear way, to the variation of deformation imposed on 12. More specifically, the potential difference depends on the velocity of deformation of the piezoelectric layer 12.

This state of deformation of the piezoelectric layer 12 occurs every time a displacement of that part of the tyre to which the piezoelectric cable 10 is attached or in which it is embedded is propagated to the cable 10 and hence to the layer 12.

Therefore, when the vehicle is travelling and the tyre 1 is rolling over a surface, an electric voltage (potential difference) is produced in the cable 10 proportional to the variants of its deformations. In the graph, Fig. 8, the amplitude (millivolts) of the voltage over time (sec) is shown for a piezoelectric cable 10 having an electrical capacitance equal to 700 pF/m (picofaradays per metre) and a piezoelectric coefficient  $d_{3h}$  of 0.15 pC/N (picocoulombs per Newton), attached to a tyre rolling at a velocity of 80 km/h.

The piezoelectric cable 10 is electrically connected by conductors 16 to a device 15 capable of storing the electrical energy produced (Fig. 6). The device 15 may consist of, for example, a capacitor/rechargeable battery that acts as a buffer battery and is mounted on the inside surface 7 of the carcass (Fig. 2) or inside the rim 8. In the latter case the electrical circuit is attached not only to the tyre but also therefore to the rim 8.



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This provides a constant source of power because the piezoelectric cable 10 is used as a "dynamo" that generates electrical energy and the energy produced is stored in the capacitor/rechargeable battery 15.

The central core 11 and the conductor 13 of the cable 10 are connected electrically not only to the capacitor/rechargeable battery 15 but also to other components of an electrical circuit. These components, which use the electrical energy generated by the cable 10, consist of sensors, transmitters or sensor/transmitters, one of which is indicated at 18 in Fig. 7.

Fig. 9 shows the amplitude of the voltage (volts) generated by two types of piezoelectric cable arranged in line along the internal equatorial circumference of a tyre as the rolling velocity (km/h) varies. In the case of curve a the piezoelectric cable had an electric capacitance of 800 pF/M and a piezoelectric coefficient  $d_{3h}$  of 1.5 pC/N. In the case of curve b the piezoelectric cable had an electric capacitance of 700 pF/m and a piezoelectric coefficient  $d_{3h}$  of 0.15 pC/N.

## CLAIMS

1. System for generating electrical energy in a vehicle tyre (1) comprising at least one piezoelectric element (9; 109) associated to the said tyre (1) which generates electrical energy whenever it is deformed, the said tyre (1) also comprising a carcass (2) and a tread (3) and being mounted on a vehicle wheel rim (8), characterized in that the said at least one piezoelectric element (9; 109) is elongate, extends along at least a portion of the said tyre (1) and is connected electrically to an electrical circuit that is applied to the said tyre (1) and is not in electrical communication with the vehicle.
2. System according to Claim 1, characterized in that the said electrical circuit comprises a sensor (18) for monitoring and controlling the performance of the tyre and/or of the vehicle.
3. System according to Claim 2, characterized in that the said sensor (18) is selected from pressure, temperature, force, velocity sensors and the like.
4. System according to Claim 2, characterized in that the said electrical circuit comprises a transmitter (18) that transmits out of the tyre the data collected by the said sensor.
5. System according to Claim 4, characterized in that the said transmitter (18) is operationally connected to a receiver installed in the vehicle.
6. System according to Claim 5, characterized in that the said transmitter (18) is a radio transmitter.
7. System according to Claim 1, characterized in that the said electrical circuit includes a device (15) that stores the electrical energy produced by the said piezoelectric element (9; 109).

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8. System according to Claim 7, characterized in that the said storage device (15) is a capacitor/rechargeable battery assembly that acts as a buffer battery.
9. System according to Claim 1, characterized in that the said at least one elongate piezoelectric element (9; 109) extends along at least a portion of the circumference of the said tyre (1).
10. System according to Claim 1, characterized in that the said elongate piezoelectric element (109) follows an undulated path along the circumference of the said tyre (1).
11. Tyre (1) for a vehicle comprising at least one piezoelectric element (9; 109) that generates electrical energy whenever it is deformed, the said tyre (1) also comprising a carcass (2) and a tread (3) and being characterized in that the said at least one piezoelectric element (9; 109) is elongate, extends along at least a portion of the said tyre (1) and is connected electrically to an electrical circuit that is applied to the said tyre (1) and is not in electrical communication with the vehicle.
12. Tyre (1) according to Claim 11, characterized in that the said electrical circuit comprises a sensor (18) for monitoring and controlling the performance of the tyre and/or of the vehicle.
13. Tyre (1) according to Claim 12, characterized in that the said sensor (18) is selected from pressure, temperature, force, velocity sensors and the like.
14. Tyre (1) according to Claim 12, characterized in that the said electrical circuit comprises a transmitter (18) that transmits out of the tyre the data collected by the said sensor.
15. Tyre (1) according to Claim 14, characterized in that the said transmitter (18) is operationally connected to a receiver installed in the vehicle.

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16. Tyre (1) according to Claim 15, characterized in that the said transmitter (18) is a radio transmitter.
17. Tyre (1) according to Claim 11, characterized in that the said electrical circuit includes a device (15) that stores the electrical energy produced by the said piezoelectric element (9; 109).
18. Tyre (1) according to Claim 17, characterized in that the said storage device (15) is a capacitor/rechargeable battery assembly that acts as a buffer battery.
19. Tyre (1) according to Claim 11, characterized in that the said at least one elongate piezoelectric element (9; 109) extends along at least a portion of the circumference of the said tyre (1).
20. Tyre (1) according to Claim 11, characterized in that the said elongate piezoelectric element (109) follows an undulated path along the circumference of the said tyre (1).

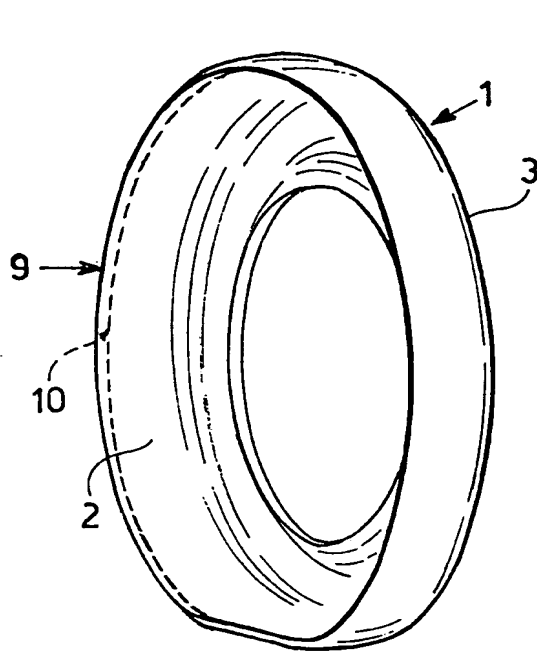


Fig. 1

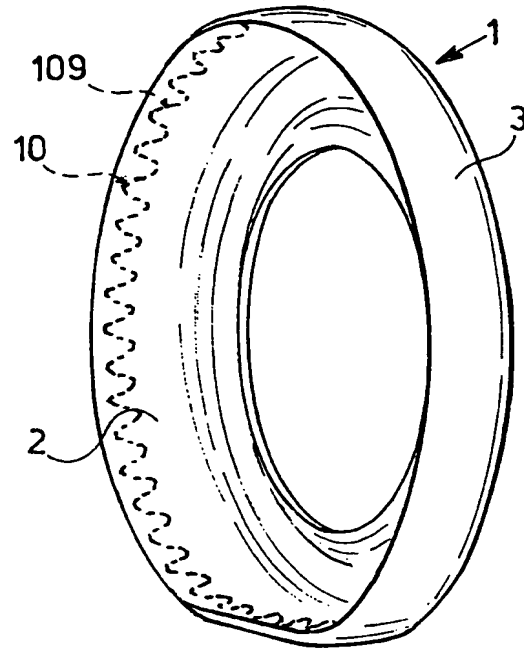


Fig. 3

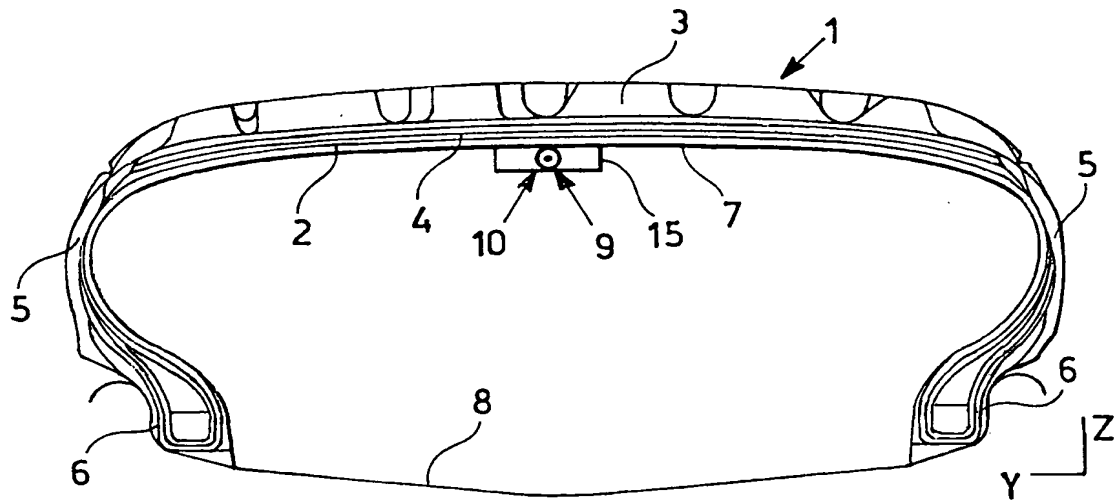


Fig. 2

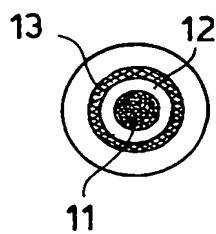


Fig. 4

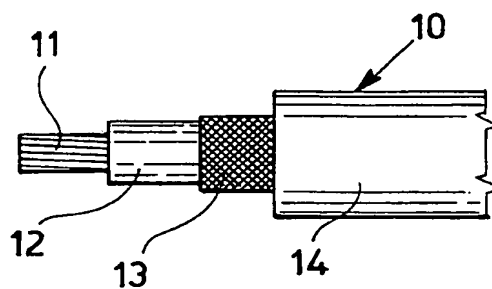


Fig. 5

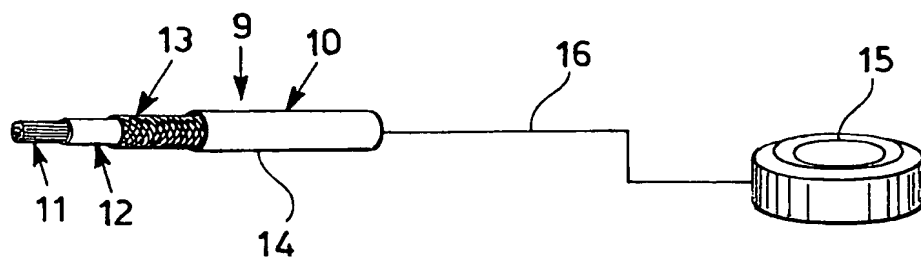


Fig. 6

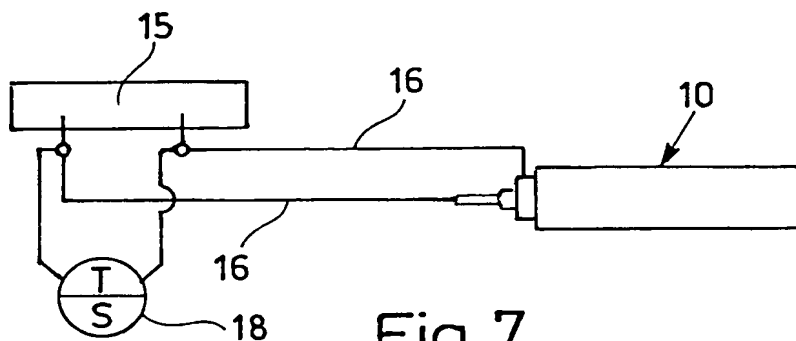


Fig. 7

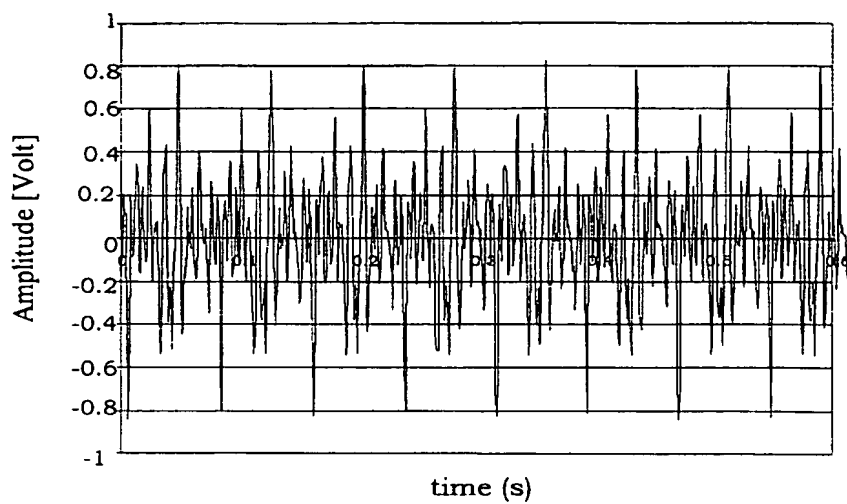


FIG. 8

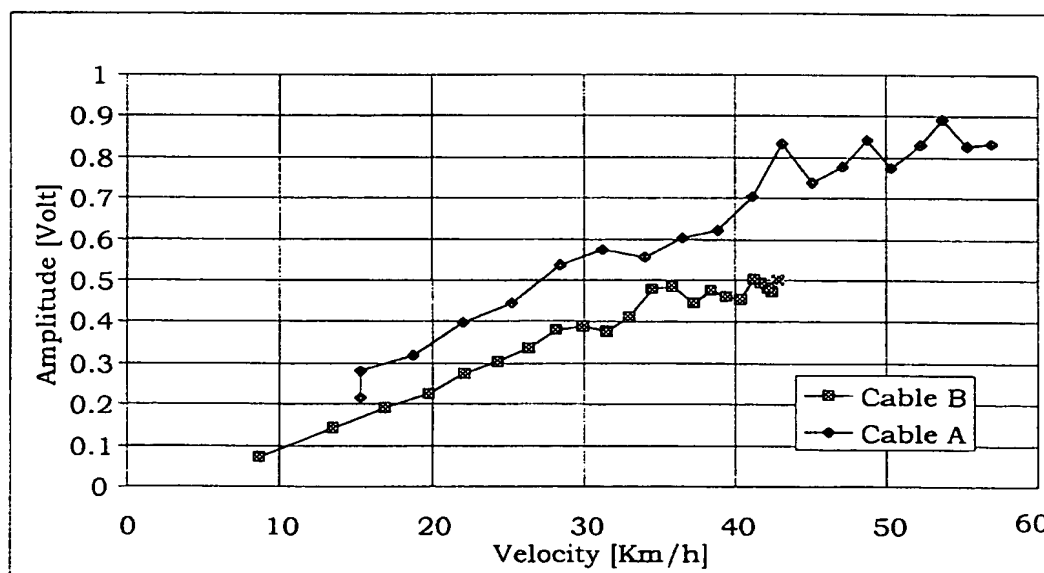


FIG. 9

## INTERNATIONAL SEARCH REPORT

International Application No.

PCT/EP 01/04210

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 H01L41/113 B60C23/06 B60C23/04 B60C23/20

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H01L B60C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

INSPEC, COMPENDEX, EPO-Internal, WPI Data, PAJ

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	FR 2 580 997 A (RAMBAUD GUY R) 31 October 1986 (1986-10-31)  the whole document ---	1,7-9, 11,17-19 2-6, 12-16
Y A	US 4 300 119 A (WIERNICKI MICHAEL V) 10 November 1981 (1981-11-10)  the whole document ---	2-6, 12-16 1,11
Y A	DE 44 02 136 A (TEMIC TELEFUNKEN MICROELECTRONIC GMBH; CONTINENTAL AG (DE)) 27 July 1995 (1995-07-27)  column 1 -column 4 -----	2-4, 12-14  1,11



Further documents are listed in the continuation of box C.



Patent family members are listed in annex.

## \* Special categories of cited documents:

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Date of the actual completion of the international search

17 September 2001

Date of mailing of the international search report

24/09/2001

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# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/EP 01/04210

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
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